A STUDY OF MATERIALS WITH ELECTRICAL PROPERTIES OF SEA ICE

by

Jonathan W. Bredow and Adrian K. Fung

Wave Scattering Research Center
Department of Electrical Engineering
PO Box 19016
Arlington, TX 76019

N00014-94-1-0805

Final Report

for

Department of the Navy
Office of the Chief of Naval Research
Arlington, Virginia 22217-5000

A STUDY OF MATERIALS WITH ELECTRICAL PROPERTIES OF SEA ICE

Jonathan W. Bredow and Adrian K. Fung

Wave Scattering Research Center
PO Box 19016
Arlington, Texas 76019
(817)-273-3497

1.0 Introduction

The research presented here investigated materials with permittivities similar to those of sea ice over the microwave frequency range. These materials will be used in future synthetic targets to study and quantify various scattering mechanisms considered to be of importance in sea ice. They will also be used in assessing the behavior of inverse models, i.e., models for retrieving ice physical and electrical characteristics from remote sensing data. The report presents the types of materials investigated, general mechanical characteristics and results of investigations to control permittivities within the range exhibited by sea ice.

2.0 Discussion of Materials Investigated

We investigated materials that can be made in the laboratory without specialized chemical or mechanical processing equipment. The investigation really focused on easily manipulable plastics and solid hydrocarbons that have permittivity magnitudes around 2.5 to 3.5, i.e., similar to sea ice. These materials included epoxy, metal-filled epoxy, RTV and neoprene caulking compounds, polyester casting compound, paraffin wax and beeswax. Filler materials were then inserted in various quantities to assess changes in dielectric constant magnitude and loss tangent. The filler materials that were used generally have high permittivities and/or loss and include mica, aluminum oxide, titanium dioxide, carbon black and carbon powder.

Before electrical characterization was done some materials were eliminated as possible candidates due to their undesirable mechanical properties. In particular the caulking compounds and the metal-filled epoxies did not harden well enough or in a timely fashion when produced in thick layers (5 cm). This would cause problems down the line with inserting scatterers in the medium and in handling and storage. The remaining compounds performed well mechanically.

A summary of findings dealing with permittivity control for each of the materials investigated is included in the form of tables and figures on pages 3 through 19. Here we provide a brief description of those. Page 3 provides a summary of the dielectric behaviors of the candidate materials before fillers are added. Epoxy and polyester casting compound are preferred due to their mechanical rigidity and dielectric constant magnitudes near 3, i.e., near that of sea ice. As a result, the work focused on these materials. Beeswax and paraffin have a desirable low loss characteristic, however. The

frequency behaviors of 2 types of epoxy and polyester casting compound are illustrated on page 4.

Pages 5-9 show the effects of various types and quantities of fillers in Shell EPON 828 epoxy. Aluminum oxide (pg. 5), titanium dioxide (pg. 6), and carbon black (pg. 8) show similar behaviors of increasing real dielectric component with increasing filler concentration, although the manner of change is distinctly different for each of the materials. The imaginary dielectric component either remains steady or increases slightly with increase in filler concentration. On the other hand, as the concentration of mica (pg. 7) is increased the real dielectric component initially falls and then rises slightly although not back to the zero concentration level. This behavior is apparently the result of the very low density of the mica material that was used. A dramatically different behavior was observed when carbon powder was added to the epoxy (pg. 9). In this case the increases in both real and imaginary dielectric components are much more dramatic than for the other filler materials used.

Pages 10-14 show the effects of various types and quantities of fillers in Behr Super Gloss 50 epoxy. Using the same concentrations of fillers as was used for the Shell epoxy above gave substantially different results. For aluminum oxide (pg. 10) and titanium dioxide (pg. 11) as filler concentration was increased the real dielectric component initially increased but then tailed off as the concentration was further increased. Notice the much higher dielectric value for Behr epoxy with titanium dioxide filler as compared with Shell epoxy for the same filler concentration. The mica filler (pg. 12) gave similar results for both types of epoxy. With carbon black (pg. 13) a higher dielectric value was achieved for the Behr material than for the Shell material, although the carbon powder (pg. 14) exhibited substantially less effect on the Behr material in comparison to the Shell material.

Pages 15-19 show the effects of various types and quantities of fillers in the polyester casting compound. For this material the effects of adding aluminum oxide (pg. 15) and titanium dioxide (pg. 16) are similar as to what was observed for the Behr epoxy. Notice, however, the dramatic difference in the imaginary dielectric components. For polyester casting compound much higher imaginary components result when titanium dioxide is added. The effect of adding mica (pg. 17) is much the same as what was seen for the epoxy materials. The behaviors obtained by adding carbon black (pg. 18) and carbon powder (pg. 19) are similar to those obtained using similar filler concentrations with Behr epoxy. The values are noticeably higher for the polyester casting compound, however.

3.0 Conclusions

In these investigations we have found suitable materials for fabricating targets with dielectric values similar to those found for sea ice. With these materials targets can be built with a constant dielectric value or one layer at a time to generate a permittivity profile similar to what occurs in natural sea ice. Further, these materials are well-suited for machining, e.g., drilling so that various scatterers such as foam and metallic spheres can be inserted. This is important for some of the sea ice experiments we plan to perform.

Selected Summary of Material Properties

	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
ε'	3.09	3.08	3	2.94	2.91	2.93
ε"	.09	.16	.21	.21	.19	.19

Shell 828 Epoxy

	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
ε'	3.15	3.13	3.05	3	2.97	2.99
ε"	.07	.17	.22	.21	.19	.18

BEHR Super Gloss 50 Epoxy

	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
ε'	3.2	3.17	3.08	3.01	2.97	3.02
ε"	.05	.16	.22	.21	.17	.15

Clear Polyester Casting Compound

	3 GHz	6 GHz
ε'	1.83	1.84
ε"	0.025	0.065

Bee's Wax

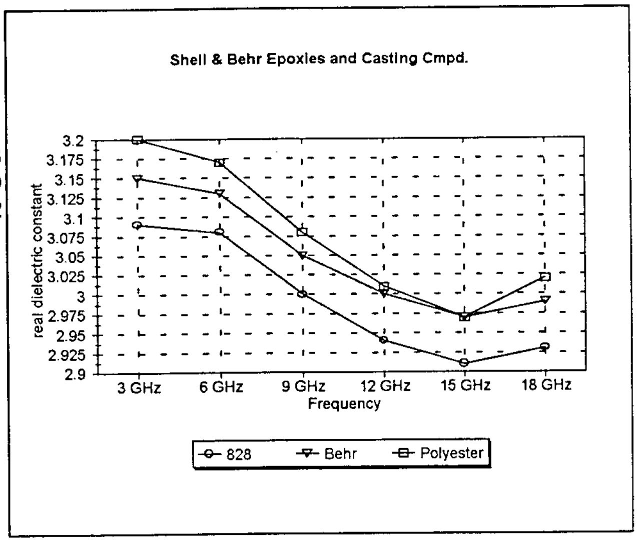
	3 GHz	6 GHz
ε'	2.13	2.16
ε"	0.015	0.07

153° Parafin

Shell EPON 828 Epoxy (828)
Behr Super Gloss 50 (Behr)
Clear Polyester Casting Compound (Polyester)

Real Dielectic Constant

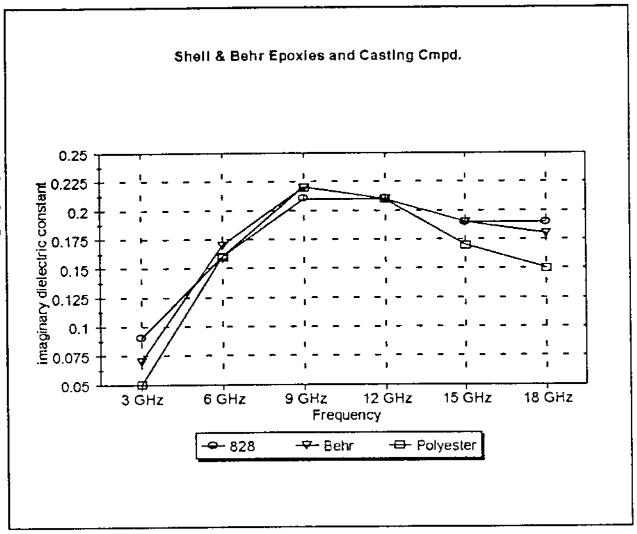
	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
828	3.09	3.08	3.00	2.94	2.91	2.93
Behr	3.15	3.13	3.05	3.00	2.97	2.99
Polyester	3.20	3.17	3.08	3.01	2.97	3.02



Shell EPON 828 Epoxy (828)
Behr Super Gloss 50 (Behr)
Clear Polyester Casting Compound (Polyester)

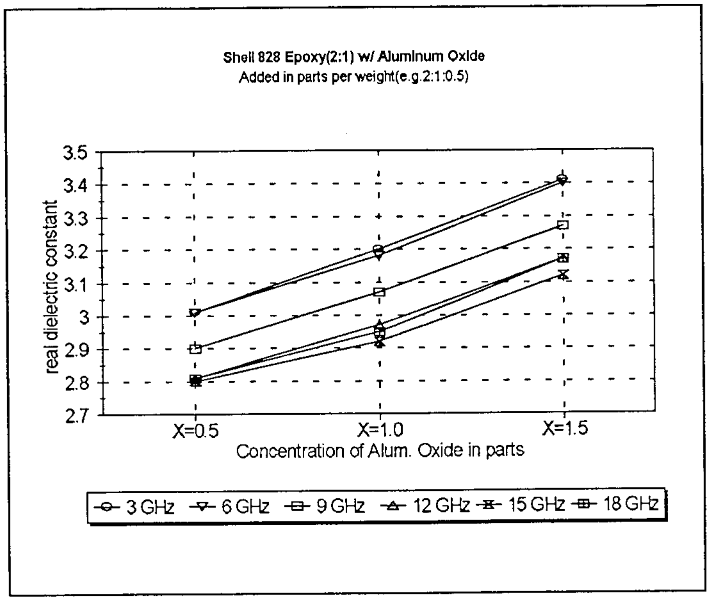
Imaginary Dielectic Constant

	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
828	0.09	0.16	0.21	0.21	0.19	0.19
Behr	0.07	0.17	0.22	0.21	0.19	0.18
Polyester	0.05	0.16	0.22	0.21	0.17	0.15



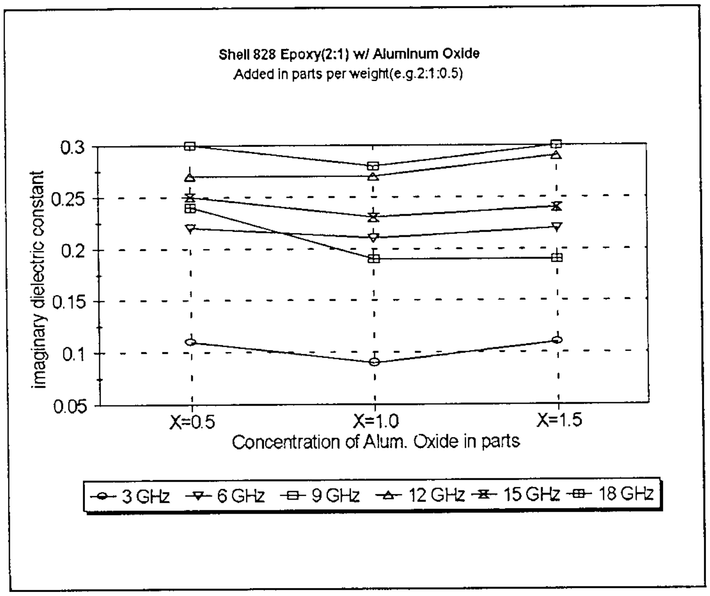
Shell EPON 828 Epoxy
with Aluminum Oxide
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	3.01	3.01	2.90	2.81	2.80	2.81
X=1.0	3.20	3.18	3.07	2.97	2.92	2.95
X=1.5	3.41	3.40	3.27	3.17	3.12	3.17



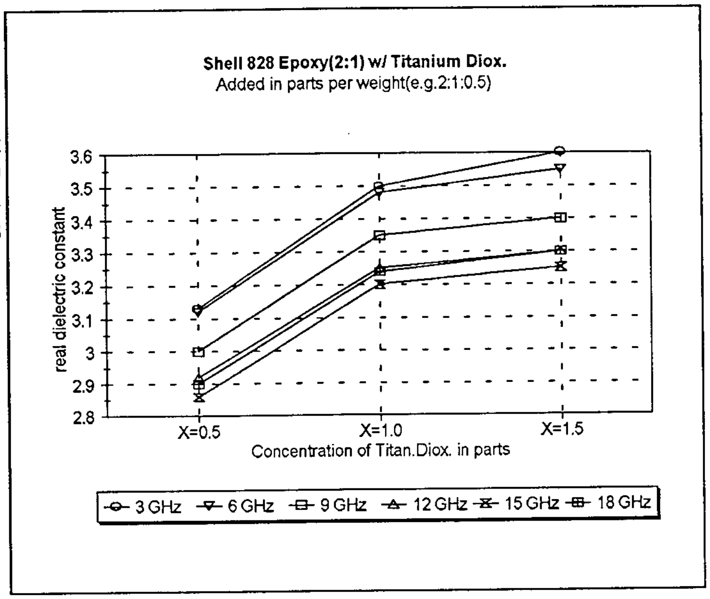
Shell EPON 828 Epoxy
with Aluminum Oxide
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	0.11	0.22	0.3	0.27	0.25	0.24
X=1.0	0.09	0.21	0.28	0.27	0.23	0.19
X=1.5	0.11	0.22	0.3	0.29	0.24	0.19



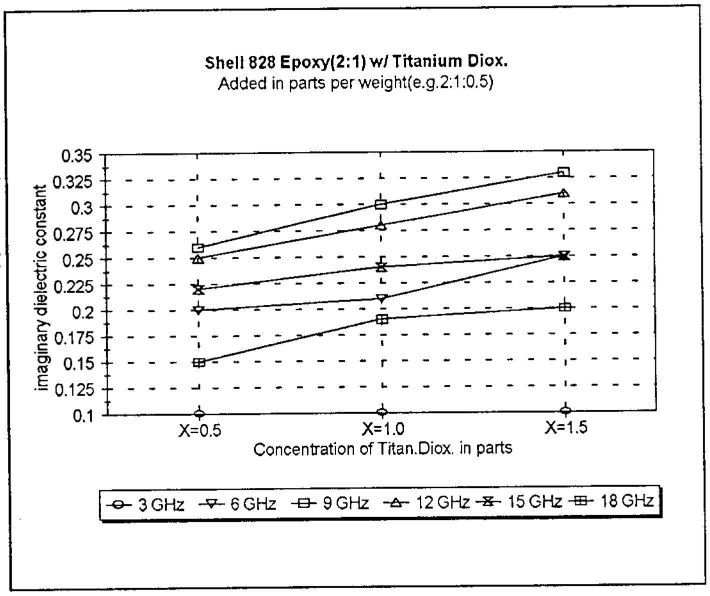
Shell EPON 828 Epoxy
with Titanium Dioxide
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	3.13	3.12	3	2.92	2.86	2.9
X=1.0	3.5	3.48	3.35	3.25	3.2	3.24
X=1.5	3.6	3.55	3.4	3.3	3.25	3.3



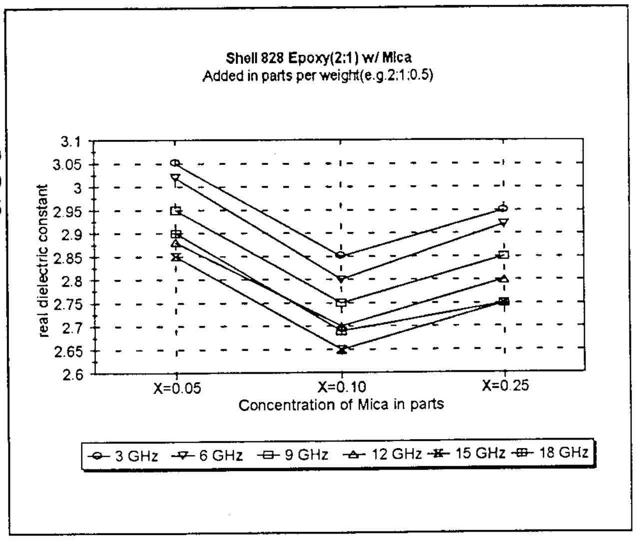
Shell EPON 828 Epoxy
with Titanium Dioxide
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	0.1	0.2	0.26	0.25	0.22	0.15
X=1.0	0.1	0.21	0.3	0.28	0.24	0.19
X=1.5	0.1	0.25	0.33	0.31	0.25	0.2



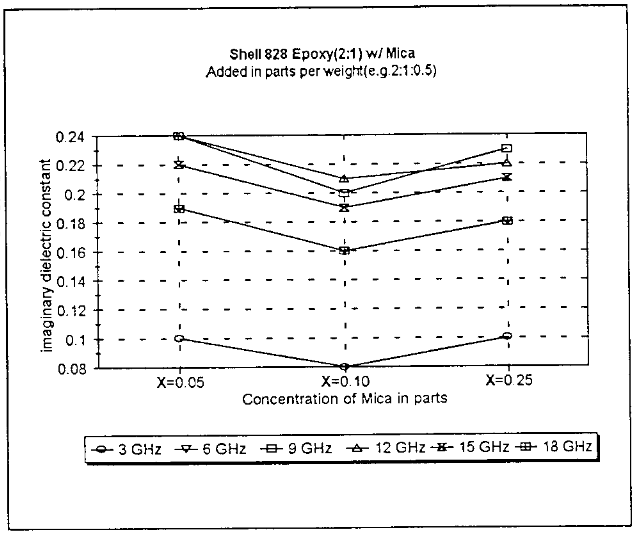
Shell EPON 828 Epoxy
with Mica
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.05	3.05	3.02	2.95	2.88	2.85	2.9
X=0.10	2.85	2.8	2.75	2.7	2.65	2.69
X=0.25	2.95	2.92	2.85	2.8	2.75	2.75



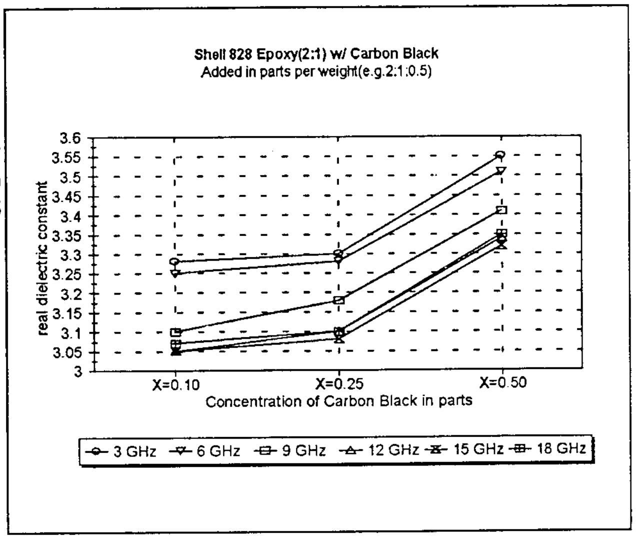
Shell EPON 828 Epoxy
with Mica
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.05	0.1	0.19	0.24	0.24	0.22	0.19
X=0.10	0.08	0.16	0.2	0.21	0.19	0.16
X=0.25	0.1	0.18	0.23	0.22	0.21	0.18



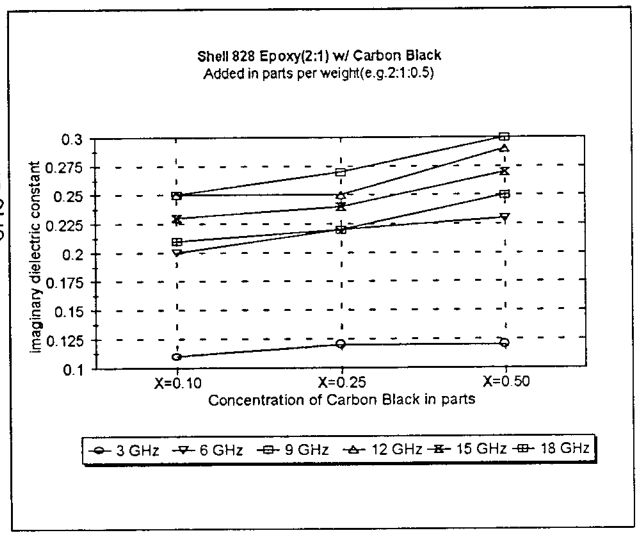
Shell EPON 828 Epoxy
with Carbon Black
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.10	3.28	3.25	3.10	3.05	3.05	3.07
X=0.25	3.30	3.28	3.18	3.10	3.08	3.10
X=0.50	3.55	3.51	3.41	3.34	3.32	3.35



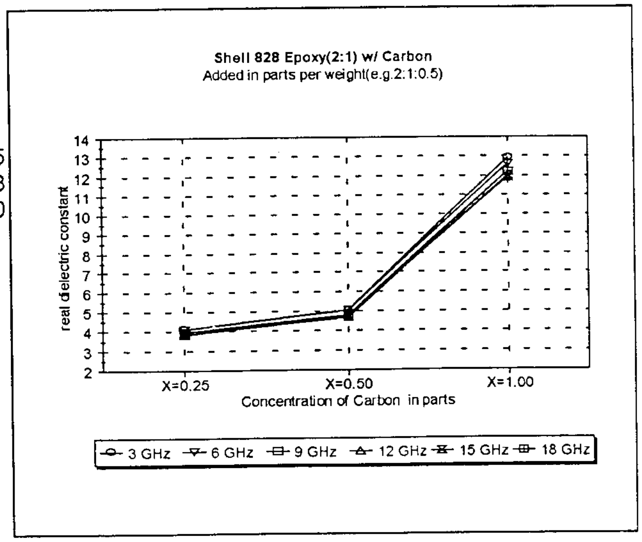
Shell EPON 828 Epoxy
with Carbon Black
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.10	0.11	0.20	0.25	0.25	0.23	0.21
X=0.25	0.12	0.22	0.27	0.25	0.24	0.22
X=0.50	0.12	0.23	0.30	0.29	0.27	0.25



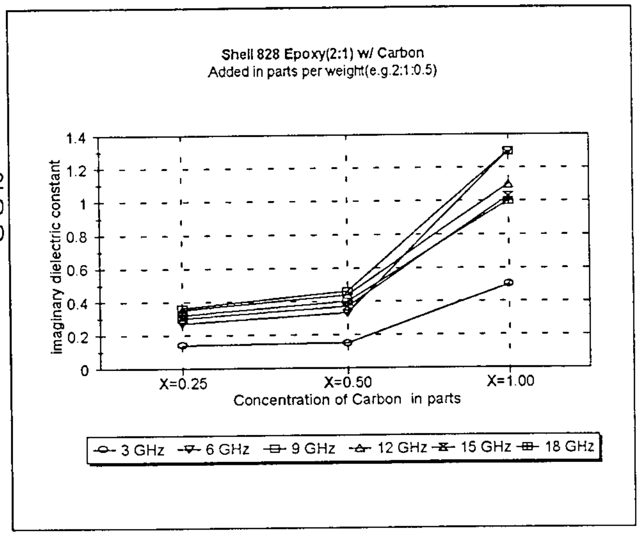
Shell EPON 828 Epoxy
with Carbon
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.25	4.10	4.09	3.95	3.84	3.82	3.85
X=0.50	5.06	5.05	4.80	4.70	4.68	4.68
X=1.00	12.90	12.60	12.20	11.90	12.00	12.20



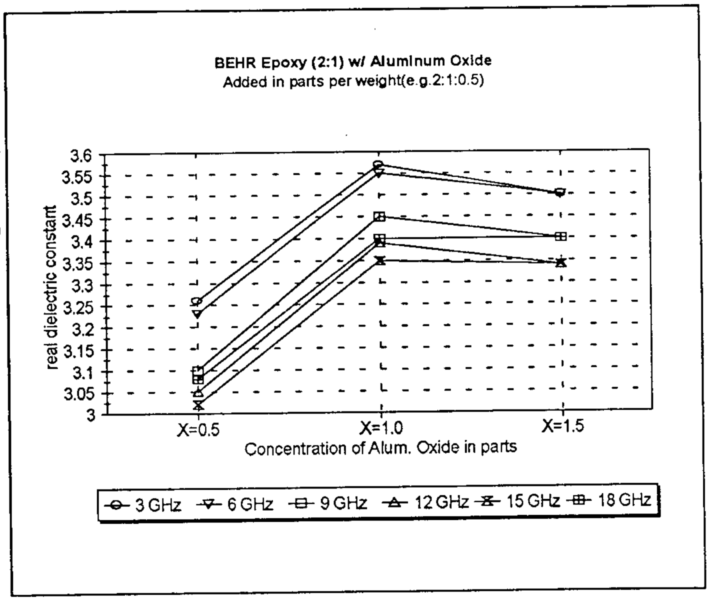
Shell EPON 828 Epoxy
with Carbon
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.25	0.14	0.27	0.36	0.35	0.30	0.32
X=0.50	0.15	0.33	0.46	0.44	0.37	0.40
X=1.00	0.50	1.30	1.30	1.10	1.03	1.00



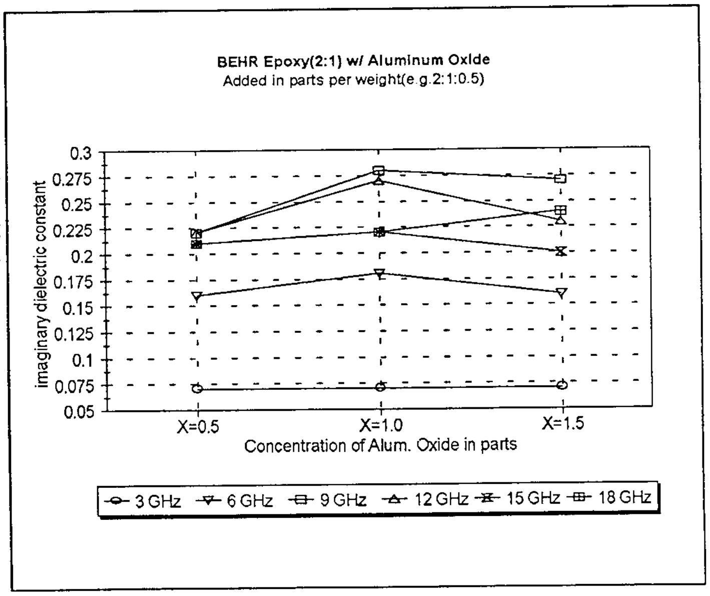
BEHR Super Gloss 50 Epoxy
with Aluminum Oxide
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	3.26	3.23	3.10	3.05	3.02	3.08
X=1.0	3.57	3.55	3.45	3.39	3.35	3.40
X=1.5	3.50	3.50	3.40	3.34	3.34	3.40



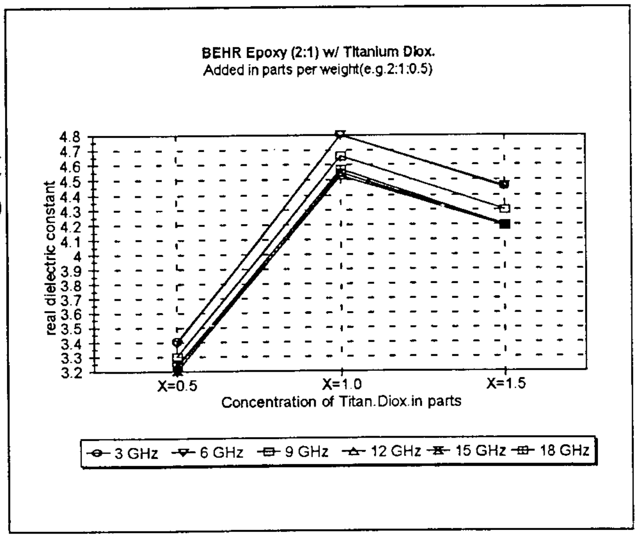
BEHR Super Gloss 50 Epoxy
with Aluminum Oxide
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	0.07	0.16	0.22	0.22	0.21	0.21
X=1.0	0.07	0.18	0.28	0.27	0.22	0.22
X=1.5	0.07	0.16	0.27	0.23	0.20	0.24



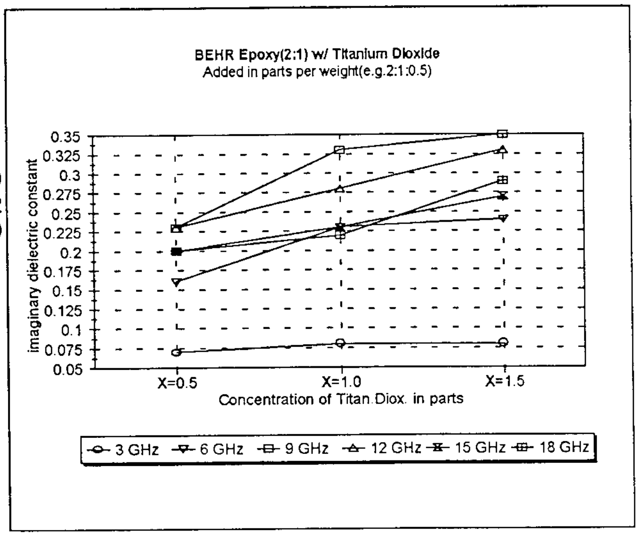
BEHR Super Gloss 50 Epoxy
with Titanium Dioxide
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	3.40	3.39	3.30	3.23	3.20	3.24
X=1.0	4.80	4.80	4.66	4.53	4.55	4.57
X=1.5	4.45	4.46	4.30	4.19	4.19	4.20



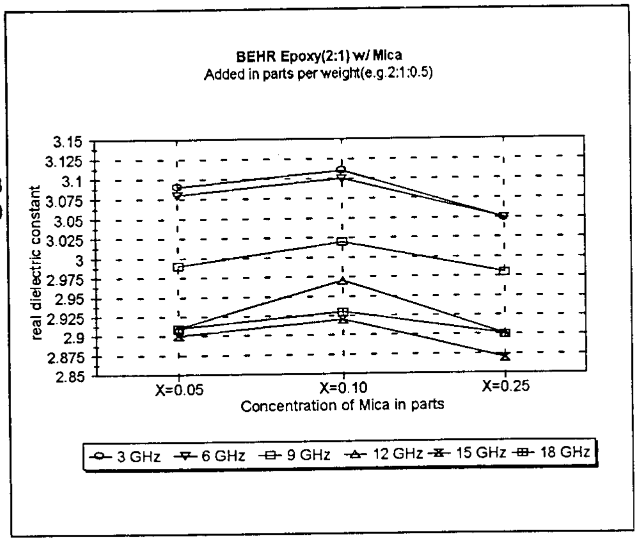
BEHR Super Gloss 50 Epoxy
with Titanium Dioxide
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	0.07	0.16	0.23	0.23	0.20	0.20
X=1.0	0.08	0.23	0.33	0.28	0.23	0.22
X=1.5	0.08	0.24	0.35	0.33	0.27	0.29



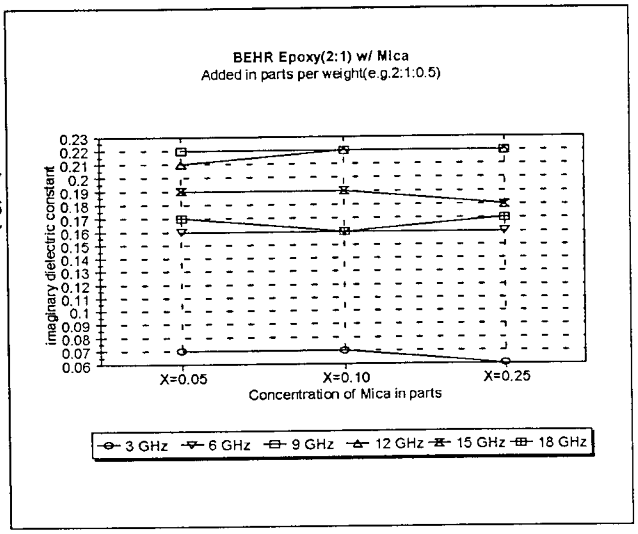
BEHR Super Gloss 50 Epoxy
with Mica
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.05	3.09	3.08	2.99	2.91	2.90	2.91
X=0.10	3.11	3.10	3.02	2.97	2.92	2.93
X=0.25	3.05	3.05	2.98	2.90	2.87	2.90



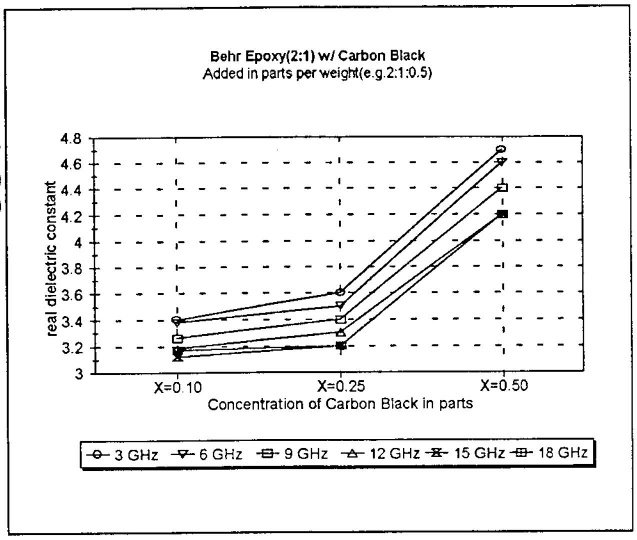
BEHR Super Gloss 50 Epoxy
with Mica
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.05	0.07	0.16	0.22	0.21	0.19	0.17
X=0.10	0.07	0.16	0.22	0.22	0.19	0.16
X=0.25	0.06	0.16	0.22	0.22	0.18	0.17



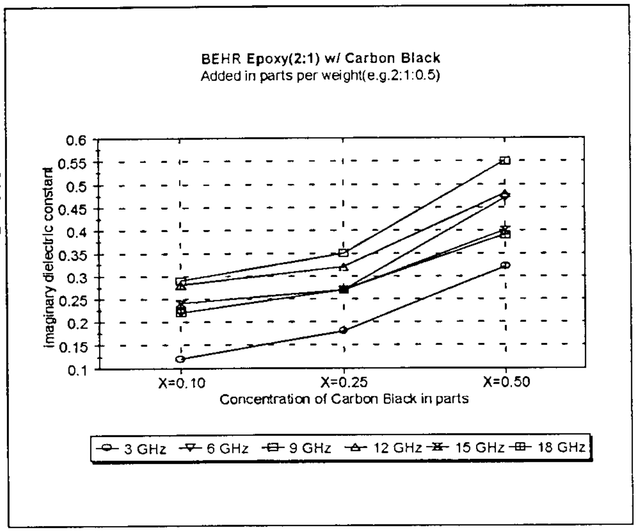
BEHR Super Gloss 50 Epoxy
with Carbon Black
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.10	3.40	3.38	3.26	3.18	3.12	3.17
X=0.25	3.60	3.50	3.40	3.30	3.20	3.20
X=0.50	4.70	4.60	4.40	4.20	4.20	4.20



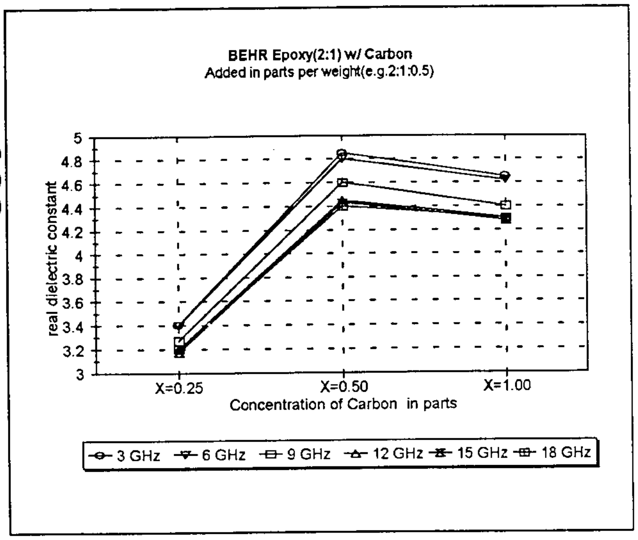
BEHR Super Gloss 50 Epoxy
with Carbon Black
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.10	0.12	0.22	0.29	0.28	0.24	0.22
X=0.25	0.18	0.27	0.35	0.32	0.27	0.27
X=0.50	0.32	0.47	0.55	0.48	0.40	0.39



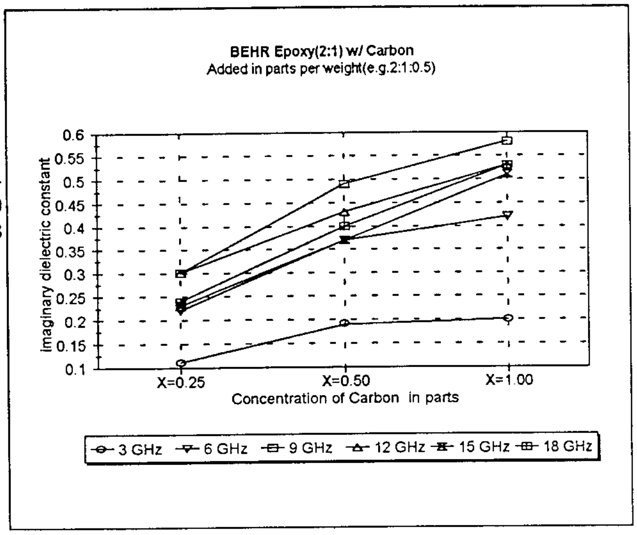
BEHR Super Gloss 50 Epoxy
with Carbon
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.25	3.40	3.40	3.27	3.20	3.17	3.20
X=0.50	4.85	4.80	4.60	4.45	4.43	4.40
X=1.00	4.65	4.62	4.40	4.30	4.28	4.30



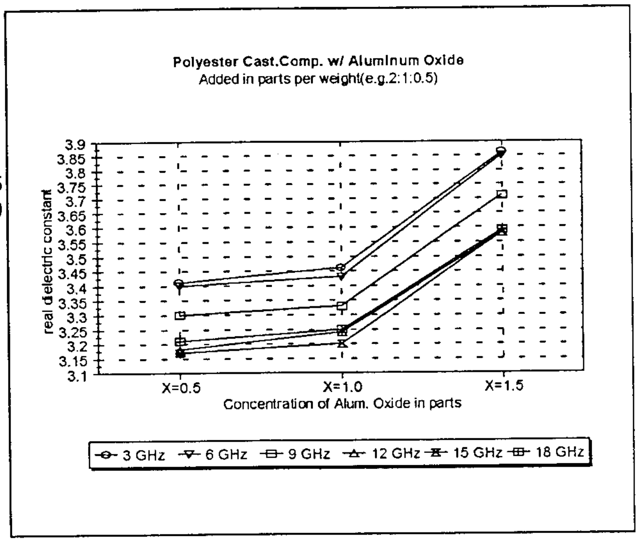
BEHR Super Gloss 50 Epoxy
with Carbon
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.25	0.11	0.22	0.30	0.30	0.23	0.24
X=0.50	0.19	0.37	0.49	0.43	0.37	0.40
X=1.00	0.20	0.42	0.58	0.53	0.51	0.53



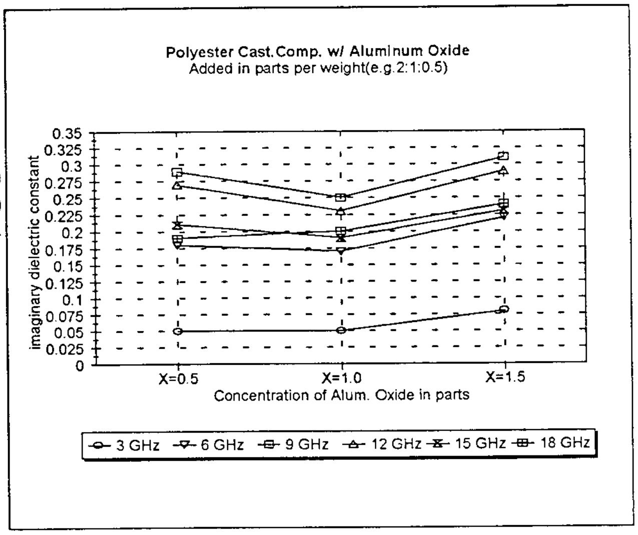
Clear Polyester Casting Compound
with Aluminum Oxide
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	3.41	3.40	3.30	3.18	3.17	3.21
X=1.0	3.46	3.43	3.33	3.24	3.20	3.25
X=1.5	3.86	3.85	3.71	3.58	3.58	3.59



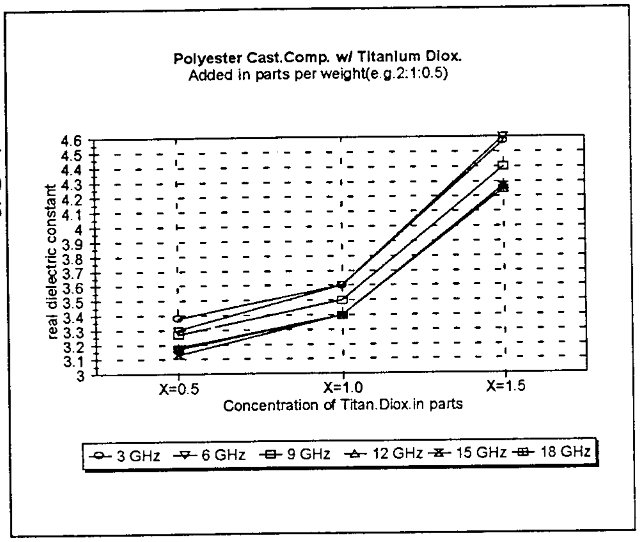
Clear Polyester Casting Compound
with Aluminum Oxide
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	0.05	0.18	0.29	0.27	0.21	0.19
X=1.0	0.05	0.17	0.25	0.23	0.19	0.20
X=1.5	0.08	0.22	0.31	0.29	0.23	0.24



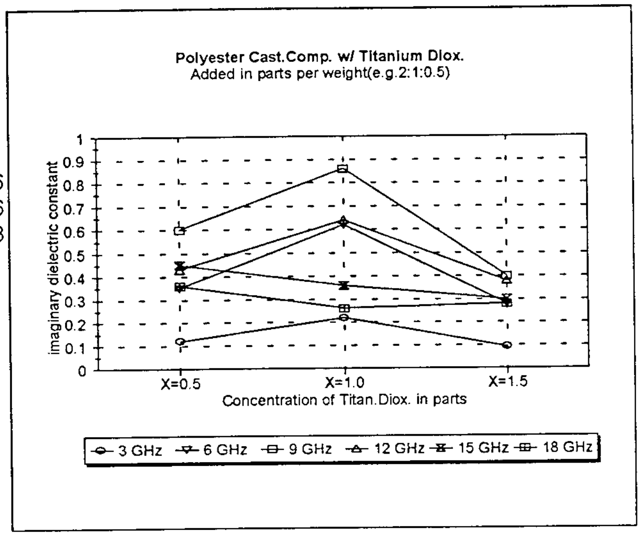
Clear Polyester Casting Compound
with Titanium Dioxide
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	3.38	3.30	3.27	3.18	3.13	3.17
X=1.0	3.60	3.60	3.50	3.40	3.40	3.40
X=1.5	4.57	4.60	4.40	4.25	4.27	4.25



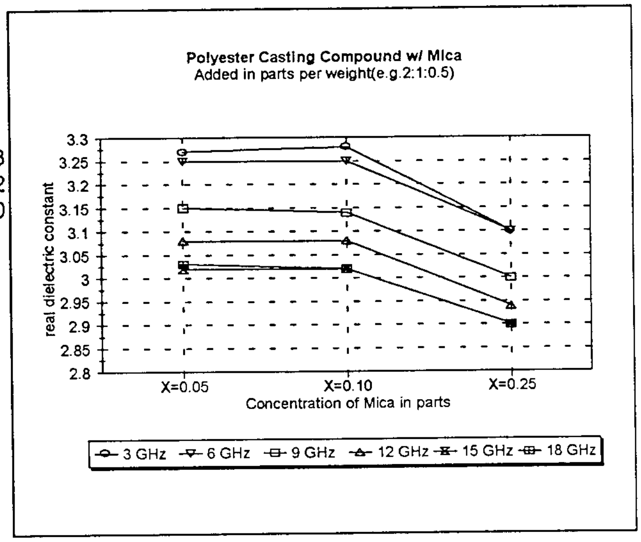
Clear Polyester Casting Compound
with Titanium Dioxide
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.5	0.12	0.35	0.60	0.43	0.45	0.36
X=1.0	0.22	0.62	0.86	0.64	0.36	0.26
X=1.5	0.09	0.28	0.40	0.38	0.30	0.28



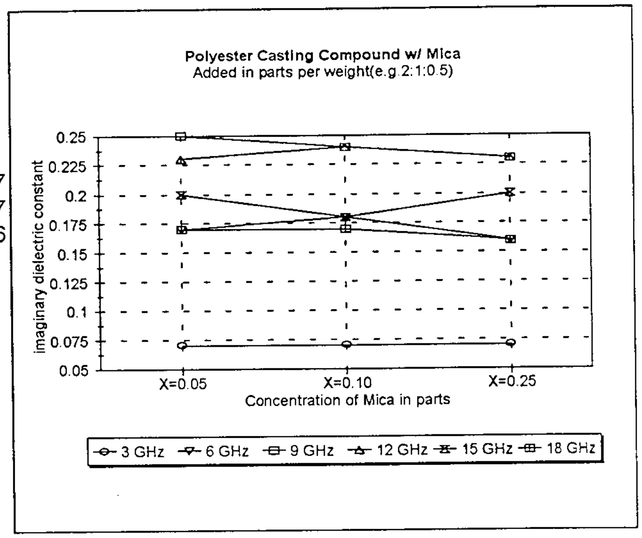
Clear Polyester Casting Compound
with Mica
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.05	3.27	3.25	3.15	3.08	3.02	3.03
X=0.10	3.28	3.25	3.14	3.08	3.02	3.02
X=0.25	3.10	3.10	3.00	2.94	2.90	2.90



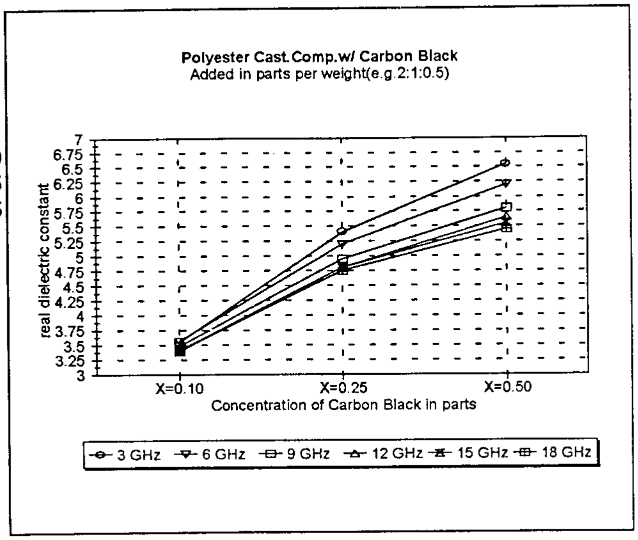
Clear Polyester Casting Compound
with Mica
Imaginary Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.05	0.07	0.17	0.25	0.23	0.2	0.17
X=0.10	0.07	0.18	0.24	0.24	0.18	0.17
X=0.25	0.07	0.16	0.23	0.23	0.2	0.16



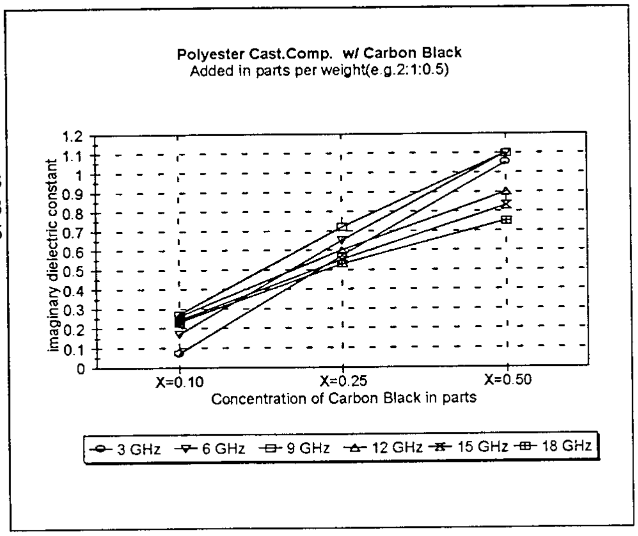
Clear Polyester Casting Compound
with Carbon Black
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.10	3.54	3.56	3.48	3.40	3.39	3.40
X=0.25	5.40	5.20	4.95	4.80	4.80	4.75
X=0.50	6.55	6.20	5.80	5.65	5.55	5.45



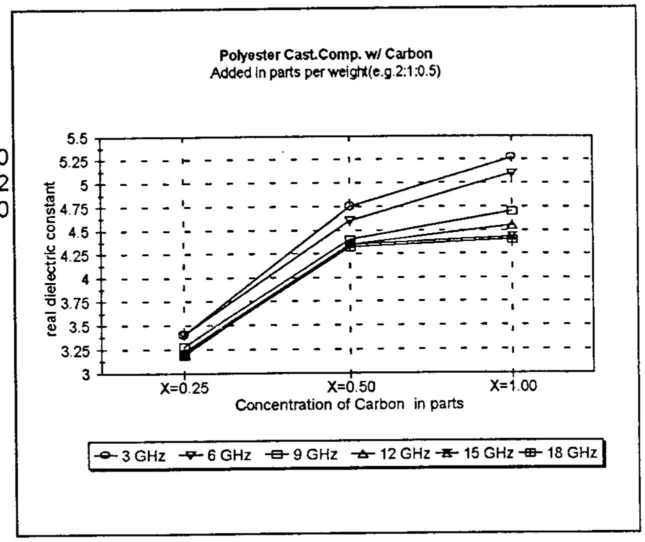
Clear Polyester Casting Compound
with Carbon Black
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.10	0.07	0.17	0.27	0.26	0.24	0.23
X=0.25	0.57	0.65	0.72	0.60	0.55	0.53
X=0.50	1.05	1.10	1.10	0.90	0.83	0.75



Clear Polyester Casting Compound
with Carbon
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.25	3.40	3.40	3.28	3.22	3.19	3.20
X=0.50	4.75	4.60	4.40	4.35	4.35	4.32
X=1.00	5.27	5.10	4.70	4.55	4.43	4.40



Clear Polyester Casting Compound
with Carbon
Real Dielectic Constant

2:1:X	3 GHz	6 GHz	9 GHz	12 GHz	15 GHz	18 GHz
X=0.25	0.06	0.17	0.24	0.25	0.23	0.20
X=0.50	0.26	0.45	0.55	0.46	0.40	0.42
X=1.00	1.12	1.35	1.35	1.10	0.93	0.73